



Quantum Leaps in Technology Transfer

More than a few of us at NIEHS were born around 1940 and recall that modern communication consisted of the telephone and the radio. Just take a trip through time, and look at the 1930 through 1990 editions of *Popular Mechanics* posted on the Internet (1). In the 1950s, a few envied families owned a black and white television, and by the 1970s color television began to replace the older sets. Fax machines and pagers began to appear in the 1980s, followed closely by cellular phones in the 1990s. The appearance of personal computers emerged in the last 10 years, but it was just in the last 2 years that software was developed enabling common use of a global system of interactive, multimedia communication, known as the Internet, which contains the World Wide Web (2). Wait till you see what comes with this technology: movie making and computer video conferencing, video phone conferencing (3), shared laboratories (4); what's next? Atlases for the Sprague-Dawley rat, rhesus monkey, and pigmy goat are available on the Internet and contain magnetic resonance images of the "sectioned" animals; video presentations of surface-skimming stoneflies can be viewed as part of a manuscript published in *Science* (5). An article by Nichols et al. in *Environmental Health Perspectives* contains a video that can be viewed on the Internet to follow the disposition of pentachloroethane as it passes from intestine to liver to kidney to fat in a rainbow trout exposed via the gills (6).

It is now estimated there are 59,000 networks and 2 million host computers in 92 countries globally, with about 1 million new Internet users added per month (7). The Internet is growing at an estimated rate of 9% to 12% a month, and has been characterized as "an unstoppable explosion" (8). If these numbers sound large, consider that unique computer identification numbers had to be increased this year from 32 bits to 128-bit IP addresses to begin to handle more than the 1 billion addresses already assigned to machines (9). This revolution is for the "masses"; it was estimated you can get wired for \$208, get a used XT with two floppy drives for \$70, a 2400-baud internal modem with free communication software for \$18, and an e-mail and Usenet new-reading account for \$10 a month (9).

Today dictionaries and textbooks are being continually updated with new words and techniques that rival the imagination of science fiction writers. Even the trademarks of new products sound like they came out of a Flash Gordon comic book. Computer software given names like Netscape, Mosaic, Spyglass (2), Prodigy, Genie, or Marvel (10) conjure up visions of futuristic spaceships that can no longer rival the real one, "Challenger." The astoundingly rapid appearance of these programs, known as browsers for the Internet, or as commercial on-line services, are indicative of the economic forces driving the development of the Internet. However, the novel concept of linking computers throughout the world was not begun for commercial use but for advances in research and development.

Thankfully, advances in computer search and retrieval have kept pace with the exponential increase in technological advances and accompanying acronyms, or it would be almost impossible to keep up with the latest developments in a particular discipline. Scientific articles are filled with the now-familiar acronyms such as tRNA, SEM, PCB, or AhR, along with myriad terms for newly discovered genes (*c-abl*, *p53*, *hsp70*, *BRCA1*, *KAI1*), or techniques

(PCR, TRAP, mAb, ELISA). Such rapid progress in science and wordsmithing has closely followed the invention of transistors, microchips, and computers. Automation of manual laboratory techniques with computers has enabled scientists to map, sequence, and discover genes and to investigate DNA damage and repair with accuracy and at rates heretofore thought impossible (11).

In the past scientists often have restricted their energies to self-imposed arenas, many spending whole lifetimes on one species, pathway, or theorem. Today, to remain knowledgeable in a cross-cutting discipline like environmental health sciences, a broad range of data available from such diverse fields as biology, chemistry, or mathematics must be retrieved, examined, and either rejected or selected as useful. Multiple computer linkages, enabled by utilization of a common language code between machines, known as SGML (standard generalized markup language) make these arduous processes feasible on the Internet. The utilization of electronic multimedia communication for technology transfer is one of the most important advancements in the 20th century.

Card catalogs, library loans, reprints, even library request searches using CD-ROMS are passé in the new world of scientific literature search and retrieval. The slaving graduate student no longer needs a carrel. With the proper hardware, software, and an individualized computer machine address, the modern scientist can design a search program that runs on the Internet, select articles that are identified as useful and obtain instant print-outs, or for convenience run the searches and download them overnight for browsing the next morning. The Sequence Retrieval System present on the Internet has been called the paragon for linked databases, interlinking some two dozen databases to merge many of the major biological databases of the world into one comprehensive structure (12).

What else is available on the Internet? Truthfully, there is so much that nobody really knows. For example, using one of the search engines, the small Lycos in this case (2), the search for "environment" yields 12,703 documents, and within that category "dioxin" gives 82 hits, 98 for "estrogen," 228 for "PCB," 291 for "*Drosophila*," 1730 for "brain," and so forth. Within each of these subcategories there are hundreds of other categories, truly a web of information. Interestingly, in tune with the free-wheeling nature of the Internet, some directories started by individuals ended up as part of global browsers, as did Yahoo (2) on Netscape. More eclectic directories are scattered about, including two of my favorites, The Squid Page (13) and Oasis (14), a Timex site that besides telling time all over the world also presents useful information about individual countries (15), and a job site that lists of hundreds of jobs available in the United States and searchable by subject such as "government" (16). Other academically useful sites include the National Academy of Sciences (17), U.S. Government Information Servers (18), the World Wide Web Virtual Library (19), with the Biosciences and Bio Index pages, the National Library of Medicine (20), the National Institutes of Health server (21), and the National Institute of Environmental Health Sciences server (4), with the *Environmental Health Perspectives* (6) and National Toxicology Program (22) home pages as examples of the many located there. Incidentally, among the NIH institutes, the NIEHS appears to be one of the leaders in development and utilization of the Internet.

A list of science publishers that can be found on the Biosciences page include Academic Press, Cold Spring Harbor Laboratory, Elsevier, Oxford University Press, and Springer-Verlag. These offerings vary in quality, ranging from no entries to lists of contents to full-fledged journal reproductions such as can be found for the

Journal of Biological Chemistry. *Scientific American* is also available on-line using the commercial America Online source (23), enabling abstract searches of articles from May 1948 to December 1993 and perusal of complete articles. AT&T Bell Laboratories is developing RightPages, an electronic library interface to enable users to view hundreds of journals ranging from *Nature* to *JAMA* to the *New England Journal of Medicine* to *Proteins*. The most complete electronic journal to date has been developed and maintained by the American Chemical Society (ACS), which has made available all 23 of its research journals. Users can view scanned issues going back to 1992 with graphics and tables. Full text searching without graphs and tables is searchable from 1982 to date, and this year ACS journals are being published directly in electronic format. From 1992 forward users can access the ACS journals using a graphical interface named SciFinder to search databases, do structural searches, and use molecular spreadsheets (7).

Environmental Health Perspectives is in the process of going on-line. The home page contains a demonstration of the layout, searching capabilities, links to other pages and servers, an automated interactive commentaries space, and examples of types of articles, complete with full graphics and cover pages as they appear in the hard copy of the monthly journal. With an on-line electronic journal, there is the added advantage of video to depict, for example, chemical distribution among tissues after xenobiotic exposure as in the Nichols et al. article (6). All of these features can be used with a browser like Netscape or Mosaic, but there are obvious links to Gopher, e-mail, bulletin boards, or to discussion groups as well. One such group formed in May of this year is "Toxicology on the Net," located on the BIOSCI server (24), which consists of scientists from the Americas and the Pacific Rim (e-mail address: toxicol@net.bio.net) or from Europe, Central Asia, and Africa (e-mail address: toxicol@daresbury.ac.uk). The opportunity for global information exchange and commentary is obvious. The availability of computerized Internet technology transfer to share the advancements of research around the world


should revolutionize the scientific process as we know it, and lead to ever rapid advances in environmental health sciences and every other avenue of scientific endeavor.

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